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Abstract

This paper introduces the classical idea about the so-called '*directed*' and '*induced*' technical change (ITC) within a *Keynesian* demand-side and *evolutionary* endogenous growth model in order to analyze the interplay among technical change, long-run economic growth and functional income distribution. An ITC process is analyzed within an Agent-Based Stock-Flow Consistent (AB-SFC) model, wherein credit-constrained heterogeneous firms choose both the *intensity* and the *direction* of the innovation towards a labor- or capital-saving choice of technique. In the long-run, the model reproduces the so-called 'Kaldor stylized facts' (i.e. with a purely labor-saving technical change), however during the transitional phase the model shows a labor-saving/capital-using innovation pattern, as the aggregate output-capital ratio decreases until it stabilizes in the long-run, as well as declining labor share for long time periods and we can ascribe these evidences mainly to the directed technical change process. In order to stress the effective role of the innovation bias on the model dynamics, we compare the baseline scenario with a '*counterfactual*' scenario wherein a '*neutral*' technical progress is at work.

JEL classification: E24, E25, O30, O35, O41.

Keywords: Agent-Based Macroeconomics, Stock-Flow Consistent Models, Induced Technical Change, Directed Innovation, Choice of Techniques, Labor Share, Growth and Distribution.

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1. Introduction

Since the inception of classical political economy the effect of technological progress upon long-run economic growth and the distribution of income among social classes represents a crucial question. For many years the bearings for modern theory of economic growth and distribution have been the empirical regularities known as '*Kaldor stylized facts*' (Kaldor 1957), and in particular the constancy of aggregate output-capital ratio and of distributive shares.

However, over the last few decades we have observed a persistent decline in the wage share together with moderate growth of real wages (especially compared to the pace of labor productivity growth) and different pattern of output-capital ratio in advanced economies.

The social and economic consequences of declining labor share, growing capital-output ratio[1] and different pattern of the rate of profit have been brought to the center of economic debate by Piketty's book (2014) and his analysis about inequalities and capital concentration in a weak growth scenario in advanced economies. The declining pattern of aggregate wage share is nowadays at the core of economic and political economy debate about the interplay among technological change, wage-bargaining, institutional factiors and distributive shares (see for example Piketty 2014, Stiglitz 2012), so as to lead many economists to highlight the evidence for '*new styilized facts*' (Stiglitz 2016 and Jones 2015).

The Organisation for Economic Co-operation and Development (OECD 2012 and OECD 2015) provides a detailed analysis of key factors proposed in literature as the main drivers of falling labor share during the last decades and special attention has been devoted to the excessive labor-saving technical change and to the discrepancies between productivity growth and real wages pattern, especially within the European Monetary Union and the US.

Within the economic literature, different explanations have been proposed in order to account for the evidence of a declining labor share mainly through neoclassical and classical '*technology-based*' or Post-keynesian '*demand-driven*' lenses. From a Post-keynesian perspective, the increasing role played by globalization and financialization in advanced economies have been identified as the main factors accounting for the declining wage share (Lavoie and Stockhammer 2012 and Stockhammer 2013), whereas within the neoclassical stream of literature both theoretical and empirical contributions mainly rely on the hypothesis of different values of '*elasticity of substitution*' between production input (labor and capital).

Also from an empirical perspective, many economists within the neoclassical stream of literature try to account for the role of technical change and its direction in affecting the declining labor share (Bentolila and Saint-Paul 2003, Bassanini and Manfredi 2014, Hutchinson and Persyn 2012, Karabarbounis and Neiman 2014). However, all of these contributions have been focused on the estimation of an elasticity of substitution between production inputs greater than one as the sole explanation of an increasing 'capital deepening' affecting in turns the labor share.

During the nineties, Acemoglu proposes a revival of the so-called '*induced*' (ITC) and '*directed*'

[1]See Stiglitz (2016) for a detailed discussion about the definition of capital-output ratio adopted by Piketty and its relation with the Kaldor facts.

technical change hypothesis, stemming from Hicks (1932), by implementing an explicit direction of technical change, i.e. biased towards skilled or unskilled labor (Acemoglu 1998) or towards labor or capital input (Acemoglu 2002 and Acemoglu 2003), in order to explain the dynamics of wages and labor share in the US and European countries. Acemoglu proposes an endogenous growth model, similar to the monopolistic competition models implemented by Romer (1989), Grossman and Helpman (1991) and Howitt and Aghion (1998), by combining the assumption of elasticity of substitution less than one with the endogenous bias of technical change towards labor or capital productivity improvement as the theoretical explanation for labor share fluctuations in the medium-run, whereas in the long-run the model exhibits constant distributive shares in line with the 'Kaldor Facts'.

On similar grounds, in order to account for fluctuations in distributive shares Jones (2005) presents a growth model implementing a production function with different values of the elasticity of substitution for short and the long-run that is, respectively, less than and equal to one.

Before Acemoglu, the ITC hypothesis has been developed along neoclassical lines during the sixties by Kennedy (1964), who proposes a growth model with the so-called 'Invention Possibility Frontier' (IPF) in order to represent the trade-off between improvements in labor or capital productivity, and then by Samuelson (1965) and Drandakis and Phelps (1966).

Moreover, from quite distant theoretical perspectives, the puzzling question about the interplay between technical change, growth and functional distribution have been also addressed along purely classical (Van Der Ploeg 1987, Foley and Michl 1999, Foley 2003b, Foley 2003a and Zamparelli 2015) or classical/evolutionary (Dumenil and Levy 2003) lines by implementing the ITC approach. On this ground, the literature about the so-called '*Marx-Biased Technical Change*' (MBTC) implements the ITC hypothesis in order to analyzes the labor-saving/capital using pattern of technical change observed in many advanced economies during the last decades.

Notwithstanding, if we accept the idea of directed input-saving technical change process induced by different paces of growth for wages and labor productivity (so-called '*Habbakkuk Hypothesis*' [2]) as one of the main explanation for declining labor share in advanced economies, an interesting puzzling question remains why the moderate growth of wages in the early eighties could have not revert the labor-saving trend of technical change pattern. Blanchard (1997), for example, explained this phenomenon with weaker bargaining power of workers and with lagged factor substitution process triggered by the 'wage push shock' after the seventies, for example within many European countries.

Recently, Stiglitz (2015) and Stiglitz and Greenwald (2015) also propose a model with directed technical change by using the Kennedy's IPF in order to show the impact of different values of the elasticity of substitution between labor and capital input upon long-run growth, distributive shares and unemployment. Stiglitz highlights how, in a fixed coefficient scenario (the one analyzed within the present model), excessive labor-saving technical change may have relevant negative effects upon

[2] In the early sixties, some contributions in the field of economic history (Salter 1962 and Habakkuk 1962) suggest the relevance of 'labor scarcity' as a key element accounting for the induced labor-saving technical change, especially in Great Britain and United States in the nineteenth century.

functional income distribution and may also reflect in excessively high levels of unemployment.
The contributions illustrated so far, are built upon a '*supply-side*' and purely technological-based approach to growth and distribution. Nevertheless, a '*demand-side*' Keynesian approach has been increasingly developed by many scholars, in order to account for the effects of aggregate demand on the dynamics of real and financial side of a monetary production economy. On this ground, a relatively new and promising literature implementing macroeconomic models with strong interdependence between demand- and supply-side and real and financial side of the economy comes from the Complex Adaptive System approach applied to economics, stemming from Arthur et al. (1997), Kirman (2010), and Delli Gatti et al. (2007). Thus, the so-called '*Keynes + Schumpeter*' (K+S) class of models (Dosi et al. 2010, Napoletano et al. 2012, Dosi et al. 2017) and the Agent-Based Stock-Flow Consistent (AB-SFC) models (Caiani et al. 2016 (Caiani et al. 2018, Caiani et al. 2017a, Caiani et al. 2017b), concentrate the analysis upon the interplay among the evolutionary endogenous growth process, income and wealth distribution, aggregate demand and credit and financial issues.

Following this stream of literature I try to exploit some insight provided by the *classical* interpretation of the ITC hypothesis by introducing it into a *Keynesian* demand-side and *evolutionary* endogenous growth model in order to suggest a possible explanation for some evidence about growth and distribution, such as persistent fluctuations of labor share. The main goal is the analysis of the interplay among technical change, long-run economic growth and functional income distribution without recurring to any distinction between short-run (Keynesian) and long-run (classical) framework[3].
I propose a single-economy version of the multi-county AB-SFC model implemented by Caiani et al. (2017a) by adding to this model a capital-good sector, following Caiani et al. (2016) and Caiani et al. (2018), and dividing the households sector into workers and capitalist agents.
The AB-SFC approach stems from the 'benchmark' model implemented by Caiani et al. (2016) and aims to integrate the Agent-Based tradition developed upon the decentralized matching protocols for interactions among heterogeneous agents (Riccetti et al. 2015) with the Stock-Flow Consistent macro modeling approach stemming by Godley and Lavoie (2006), thus allowing us to explicitly taking into account real- and financial-side stock and flow variables and the supply- and demand-side of our artificial economy.
As in Caiani et al. (2017a) and in Caiani et al. (2018), I model the evolutionary technical change process following the two steps procedure implemented by the 'K+S' models (Dosi et al. 2010), although this process takes place within the consumption-good sector (i.e. with 'disembodied' technical change). Furthermore, I introduce within this framework a *classical-fashioned* directed technical change as heterogeneous consumption-good firms choose both the *intensity* and the *direction* of the innovation towards a labor- or capital-saving choice of technique, and as they decide to

[3]For example, a '*traverse*' model has been proposed by Dumenil and Levy (1999), where two different investment behaviors are implemented depending on the time horizon: a Keynesian investment function in the short-run and a classical investment function in the long-run. Dosi et al. (2015) also propose an interesting analysis of *classical* and *Keynesian* accumulation regimes as different roots of business fluctuations.

adopt the new production technique depending on a classical *profitability criterion* (Okishio 1961, Shaikh 1978, Nakatani 1979, Shaikh 1999, Park 2001 and Shaikh 2016).
This modeling framework allows us to enrich the analysis of '*non-neutral*' technical change and its effects upon key macroeconomic variables. Indeed, many traditional directed innovation models adopt the IPF á-la-Kennedy in order to analyze the trade-off between labor or capital productivity improvements, whereas the Agent-Based approach allows us to let the '*innovation bias*' be an '*emergent property*' of the evolutionary technical change process engaged by consumption-good firms. Thus by introducing the classical-fashioned directed innovation mechanism and the profitability criterion for the choice of new techniques within the well-established tradition of evolutionary demand-driven endogenous growth we are bridging two different theoretical traditions: the directed technical change process implemented in many supply-side growth models and the localized evolutionary innovation mechanism implemented within many recent (post-) Keynesian endogenous growth models[4]. Moreover, the AB approach also allows us to present a richer dynamics for the pattern of long-run growth, productivity and functional distribution in the light of both 'Kaldor facts' and 'new' evidences. On similar grounds, Delli Gatti et al. (2006) also propose a 'supply side' Agent-Based model wherein the interplay among R&D investment, labor-saving technical change, capital accumulation, wage-profit dynamics and financial factors have been analyzed in order to reproduce Kaldor facts and Goodwin-like growth cycles. In line with their long-run findings the present model, enriched by explicitly modeling the demand-side of the economy, is able to reproduce the 'Kaldor facts' (i.e. with purely labor-saving technical change). However, during the transitional phase the model presents a labor-saving/capital-using innovation pattern, as the aggregate output-capital ratio decreases until it stabilizes in the long-run, as well as declining labor share for long time periods. We can ascribe these findings to the directed and biased technical change process and in order to stress the effective role of the innovation bias, the baseline scenario has been compared with a '*counterfactual*' scenario wherein a '*neutral*' technical progress is at work.

2. The Model

The model is populated by K firms producing a homogeneous capital good, only using labor input, and C consumption firms producing a homogeneous final good over two inputs (labor and capital). Consumption-good firms also innovate their production process in order to save the (relatively) expensive production input and try to obtain some profitability gain (Dumenil and Levy 2003, Foley and Michl 1999, Foley 2003b, Zamparelli 2015, Stiglitz 2015).
Household sector is composed by two classes of agents: workers and capitalists. Workers sell their labor force to the capital and consumption firms and capitalists represent the equity investors (i.e.

[4]Acemoglu (2014) recently highlights some connection between the localized technical change framework, stemming by the Atkinson and Stiglitz 'new view' (Atkinson and Stiglitz 1969), the ITC hypothesis and the directed and biased innovation framework. Dosi and Virgillito (2016) also propose a discussion about the Atkinson and Stiglitz approach by analyzing it through '*Schumpeterian*' lenses, thus from a theoretical perspective much closer to the one embraced in the present contribution.

the firms and banks' equity owners) receiving their income in the form of dividends. All the agents within the household sector consume their income on the final good market and they save the residual amount (in the form of bank deposits or equity investment as capitalists agents).

Commercial banks offer deposit accounts to households and firms and endogenously create private money by providing loans to the consumption firms.

Our artificial economy also has a government and a central bank (see subsections 2.7 and 2.6). As in Caiani et al. (2017b) we have an endogenous entry/exit process. Thus, the simulation model starts with no firms and banks and they are progressively created during the simulation by means of investment out of capitalists' savings.

As in the SIM model, the simplest SFC model implemented by Godley and Lavoie (2006), everything starts with government public expenditure, in the form of lump-sum transfers distributed across workers and capitalists. This transfers are initially saved by households, and then begun to be invested by capitalist agents for the creation of new firms (primarily) and eventually new banks. After that the production starts and then possibly also the demand for loans by consumption firms to commercial banks.

Each period the heterogeneous agents directly interact on each market by means of decentralized matching protocols (Riccetti et al. 2015 and Caiani et al. 2016). The demand-side agents observe a random subset of suppliers, whose size is given by a fixed parameter measuring the degree of imperfect information.

2.1. The Simulation Schedule

1. Capital-good firms decide the wage to offered and the selling price;
2. Consumption firms determine the production planning by deciding the desired quantity of output, the desired quantity of labor input, the offered wages, the selling prices, the desired amount of investment in R&D and, eventually, demand for loans;
3. Commercial banks and consumption-firms interact on the credit market;
4. Final-good firms decide the accumulation plan by computing the desired growth rate of production capacity (and hence the desired quantity of capital goods);
5. Capital and consumption firms interact with workers on the labor market;
6. Capital firms interact with consumption firms in the capital goods market;
7. Workers receive their wages and are employed for the production and R&D activity. Capitalist agents receive dividends generated in the previous period;
8. Consumption-good firms undertake the innovation process and compare the new random technique with the one inherited from the previous period. Then they produce the final good;
9. Government decides the tax-rate and the public expenditure planning;
10. Bonds market interactions;
11. Households pay taxes on their income and receive the tax-exempt transfers by the Government. Then, they compute the desired consumption and interact with the final-good firms;
12. Firms compute their profits and net worth and the taxes to be paid in the next period.

Consumption firms also compute the dividends to be distributed in the next period to the equity investors (capitalists);

13. Entry/exit process. Capitalists invest and eventually create new firms and banks.

2.2. Capital-good Firms

We have $k = 1, \ldots, K$ firms (capital sector) producing each period a certain quantity of intermediate capital goods, $y^K_{k,t}$, depending on the demand requested by the consumption goods firms as capital input. Thus we have

$$y^K_{k,t} = a_k N^D_{k,t} \tag{1}$$

with a_K indicating the (constant) labor productivity for the workers employed in the capital production process and $N^D_{k,t}$ indicating the desired quantity of labor needed in order to produce the capital output.

Thus, they demand a certain quantity of labor input as follows

$$N^D_{k,t} = \frac{y^K_{k,t}}{a_K} \tag{2}$$

and decide the quantity of capital output to be produced, $y^K_{k,t}$, depending on the desired quantity requested by the consumption goods firms,

$$y^K_{k,t} = y^{KD}_{c,t}. \tag{3}$$

Capital firms adopt an adaptive wage rule depending on the wage offered in the previous period and on the difference between labor demanded and labor actually employed in the previous period (Caiani et al. 2017a), as follows:

$$w_{k,t} = \begin{cases} w_{k,t-1}(1 - U[0, \delta]), & \text{if } l^D_{k,t-1} - l_{k,t-1} = 0 \text{ with } Pr(u_t) = 1 - e^{u_t v} \\ w_{k,t-1}(1 + U[0, \delta]), & \text{if } l^D_{k,t-1} - l_{k,t-1} > 0 \end{cases} \tag{4}$$

If firms were not satisfied, that is labor demanded is greater than the employed one in $t-1$, they have a positive probability $Pr(u_t)$ of downward revising the offered wage. This probability is inversely related to the level of unemployment in the economy u_t, with a positive (fixed) parameter v indicating the strength of their relation (the lower v the higher the probability of reducing the wages).

Then, the capital firms adopt this simple pricing rule

$$p_{k,t} = (1 + \mu)\frac{w_{k,t}}{a_k} \tag{5}$$

with a fixed mark-up over the unit labor costs.

2.3. *Consumption-good Firms*

2.3.1. *Production, Prices and Wages*

We have $c = 1, \dots, C$ heterogeneous firms producing an homogeneous consumption good over two inputs (labor and capital) assuming a Leontief production function, as follows

$$y_{c,t} = \min\{u_{c,t}\varphi_{kc,t}y^K_{c,t}; \varphi_{lc,t}N_{c,t}\} \tag{6}$$

with $u_{c,t}$ indicating the degree of capacity utilization, $\varphi_{kc,t}$ and $\varphi_{lc,t}$ being, respectively, the capital and labor productivity, whereas $y^K_{c,t}$ and $N_{c,t}$ are the capital and labor input. Consumption-good firms may improve the inputs' productivity ($\varphi_{kc,t}$ and $\varphi_{lc,t}$) by means of the R&D activity, and they adopt a new production technique depending on a *profitability criterion*, that is if the expected profit rate related to the this new innovation is greater than the actual one (see subsection 2.3.2). Once the firm has chosen the production technique, it can compute the desired output and the desired quantity of labor (for simplicity, hereafter we refer again to t and $t-1$ as the actual and previous period) given, respectively, by

$$y_{c,t} = u_{c,t}\varphi_{Kc,t}y^{KD}_{c,t} = \varphi_{lc,t}N^D_{c,t} \tag{7}$$

and

$$N^D_{c,t} = u^D_{c,t}y^K_{c,t}\frac{\varphi_{kc,t}}{\varphi_{lc,t}}. \tag{8}$$

Each period, consumption firms adaptively revise prices and their expectations about selling, as follows:

$$\text{if } \overline{y}_{c,t} \geq \overline{y}^e_{c,t-1} : \begin{cases} \overline{y}^e_{c,t} = \overline{y}^e_{c,t-1}(1 + U[0,\delta]) \\ p_{c,t} = p_{c,t-1}(1 + U[0,\delta]) \end{cases} \tag{9}$$

$$\text{if } \overline{y}_{c,t} \leq \overline{y}^e_{c,t-1} \text{and } y^{tot}_{c,t-1} > \overline{y}_{c,t-1} : \begin{cases} \overline{y}^e_{c,t} = \overline{y}^e_{c,t-1}(1 - U[0,\delta]) \\ p_{c,t} = p_{c,t-1}(1 - U[0,\delta]) \end{cases} \tag{10}$$

$$\text{if } \overline{y}_{c,t} \leq \overline{y}^e_{c,t-1} \text{and } y^{tot}_{c,t-1} = \overline{y}_{c,t-1} : \begin{cases} \overline{y}^e_{c,t} = \overline{y}^e_{c,t-1}) \\ p_{c,t} = p_{c,t-1} \end{cases} \tag{11}$$

where $\overline{y}_{c,t-1}$ indicates the output sold in the previous period and $y^{tot}_{c,t} = y_{c,t-1} + inv_{c,t}$. The desired output can be computed as $y^D_{c,t} = y^e c, t(1+\theta) - inv_{c,t}$[5].

[5] The desired quantities (here of labor and output) could be lower then the effective ones, so we could have that $N^D_{c,t} \geq N_{c,t}$ and $y^D_{c,t} \geq y_{c,t}$.
The desired quantity of (fixed) capital stock is computed depending on the accumulation decision (see subsection 2.3.3).

Moreover, the selling price cannot be less than the unit labor costs (i.e. $p_{c,t} < (1+\mu)(\frac{w_{c,t}}{\varphi_{lc,t}}))^6$.

Finally, also consumption firms adopt an adaptive wage rule, as follows:

$$w_{c,t} = \begin{cases} w_{c,t-1}(1 - U[0,\delta]), & \text{if } l^D_{c,t-1} - l_{c,t-1} = 0 \text{ with } Pr(u_t) = 1 - e^{u_t v} \\ w_{c,t-1}(1 + U[0,\delta]), & \text{if } l^D_{c,t-1} - l_{c,t-1} > 0 \end{cases} \tag{12}$$

2.3.2. Innovation

Each period firms C undertake an evolutionary innovation process and they decide to adopt the new random technology only by comparing its expected profit rate with the actual one (Okishio 1961, Shaikh 1978, Nakatani 1979, Shaikh 1999, Park 2001 Shaikh 2016).
The innovation process starts after the decision about the desired investment in the R&D activity, which is a (fixed) share of the expenditure for workers (Caiani et al. 2018)

$$IN^D_{c,t} = \gamma w_{c,t} N^D_{c,t}. \tag{13}$$

Then, the innovation process takes place in two steps as in the 'K+S' tradition Dosi et al. 2010). In a first step, firms compute a Bernoulli experiment in order to determine whether the R&D activity has been successful, so we have:

$$Pr_{IN_t} = 1 - e^{-\nu INc,t} \tag{14}$$

and this probability is affected by the amount of resources invested in innovation.
Then, we have a second step were the new production technique is obtained with two random draws for the growth rate of capital and labor productivity, as follows:

$$\varphi^+_{kc,t+1} = \varphi_{kc,t}(1 + \hat{\varphi}_k) \tag{15}$$

and

$$\varphi^+_{lc,t+1} = \varphi_{lc,t}(1 + \hat{\varphi}_l) \tag{16}$$

with $\hat{\varphi}_k \sim U[-\delta,\delta]$ and $\hat{\varphi}_l \sim U[-\delta,\delta]$.
Thus, we have a symmetric support for the random draws of labor and capital productivity improvements. This allow us to let the innovation bias emerge without imposing any analytic trade-off between a labor or capital productivity improvement, i.e. without imposing an 'Invention Possibility Frontier' *á-la-Kennedy*.
As stated above, the adoption of the new technique depends on a *profitability criterion*, i.e. it is adopted only if

$$r^+_{c,t+1} > r_{c,t}. \tag{17}$$

[6] With μ indicating a (fixed) mark-up over the unit labor costs.

The profit rate is given by the ratio between the firm's profit[7] and the stock of capital, as follows:

$$\frac{\Pi^*_{c,t}}{K_{c,t}} \equiv r_{c,t} = \frac{p_{c,t}y_{c,t} - w_{c,t}N_{c,t} - p_{kc,t}y^K_{c,t} - IN_{c,t} - i^l_{c,t}L_{c,t}}{p_{kc,t}y^K_{c,t}} \tag{18}$$

with $p_{c,t}y_{c,t}$ indicating the revenues from the sales in the previous period, $w_{c,t}N_{c,t}$ and $p_{kc,t}y^K_{c,t}$ indicating, respectively, the costs of the production factors and $i^l_{c,t}L_{c,t}$ being the repayment for the loans obtained before the production process (see subsection 2.3.4).

After some substitution we obtain the profit rate inherited from t and the potential profit rate expected from the adoption of the new random technique $(\varphi^+_{kc}, \varphi^+_{lc})$ in $t+1$, as follows

$$r_{c,t} = \frac{u_{c,t}\varphi_{kc,t}[p_{c,t} - \frac{w_{c,t}}{\varphi_{lc,t}}(1+\gamma)]}{p_{kc,t}} - 1 - \frac{i^l_{c,t}L_{c,t}}{p_{kc,t}y^K_{c,t}} \tag{19}$$

and

$$r^+_{c,t+1} = \frac{u^D_{c,t+1}\varphi^+_{kc}[p_{c,t} - \frac{w_{c,t}}{\varphi^+_{lc}}(1+\gamma)]}{p_{kc,t}} - 1 - \frac{i^l_{c,t}L_{c,t}}{p_{kc,t}y^K_{c,t}} \tag{20}$$

with $\frac{w_{c,t}}{\varphi_{lc,t}} = \omega_{c,t}$, $\frac{w_{c,t}}{\varphi^+_{l}} = \omega^+_{c,t+1}$ indicating, respectively, the wage share of c without and with the adoption of the new production technique. Thus, firms compare (eq. 17) the 'old' and the 'transient' profit rate within a 'real competition' framework (Shaikh 1999, Park 2001 and Shaikh 2016).

Consumption-good firms presenting productivity gaps with respect to the sectoral average may try to catch-up by imitating the leading competitors, as follows:

$$\varphi_{xc,t+1} = \varphi_{xc,t} + U[0, \Phi_t - \varphi_{xc,t}] \text{ if } \varphi_{xc,t} < \Phi_t \tag{21}$$

with $x = \{l, k\}$.

2.3.3. Investment and Capital Accumulation

Consumption firms compute each period their desired rate of growth of productive capacity depending on their profitability and their capacity utilization compared to their 'normal' rates (as in Caiani et al. 2016, Caiani et al. 2018), as follows

$$g^D_{c,t} = \delta_1 \frac{r_{c,t-1} - \overline{r}}{\overline{r}} + \delta_2 \frac{u^D_{c,t} - \overline{u}}{\overline{u}} \tag{22}$$

with δ_1 and δ_2 representing, respectively, the investments' sensitivity to the profit rate and to the capacity utilization, and $u^D_{c,t}$ is the desired capacity utilization[8], and $\overline{r}$ and $\overline{u}$ indicating, respec-

[7] As in Caiani et al. (2016) and Caiani et al. (2018), we refer to $\Pi^*_{c,t}$ as the Operating Cash Flow, that is the firm's profit excluding the variation of the inventories (see subsection 2.3.4).

[8] Depending on the desired output $y^D_{c,t}$, that is $u^D_{c,t} = min(1, \frac{y^D_{c,t}}{y^K_{c,t}\varphi_{kc,t}})$.

tively, the 'normal' profit rate and capacity utilization rate[9]. Thus we have both a 'classical' and a 'kaleckian' engine for the investment decision undertake by consumption firms depending, respectively, on the weight given to the profit rate and the weight given to the desired degree of capacity utilization.
After the decision about $g^D_{c,t}$ and the quantity of capital, c computes the desired nominal investment, $i^D_{c,t}$, as the number of capital units needed because of the obsolescence of capital (given a fixed depreciation rate δ) and/or fill the possible gap between the current and the desired capacity. Then, the desired real investment will be $I^D_{c,t} = i^D_{c,t} p_{kc,t}$.

2.3.4. Financing Demand, Profits and Net Worth

Each final-good firms may finance its production activity with internal funds, that is its net worth, $A_{c,t}$ and/or, if necessary, with external funds, that is a desired quantity of loans[10], $L^D_{c,t}$, with an interest rate $i^l_{c,t}$ (see subsection 2.5).
The demand for loans expressed to the banking sector depends on the cost of the desired quantity of productive inputs and on the disposable internal funds, as follows

$$L^D_{c,t} = \begin{cases} w_{c,t} N^D_{c,t} + p_{kc,t} y^{KD}_{c,t} - A_{c,t}, & \text{if } w_{c,t} N^D_{c,t} + p_{kc,t} y^{KD}_{c,t} > A_{c,t} \\ 0, & \text{otherwise.} \end{cases} \tag{23}$$

The desired quantity of loans could be different from the effective amount obtained, that is we could have $L^D_{c,t} \geq L_{c,d}$, due to an insufficient amount of loans to be supplied by the banks or an individual credit rationing (production activity has the priority on the R&D expenditure).
Firms' profits are given by the difference between revenues and expenditure:

$$\Pi_{c,t} = p_{c,t} \overline{y}_{c,t} + \Delta INV_{c,t} - w_{c,t} N_{c,t} - p_{kc,t} y^K_{c,t} - IN_{c,t} - i^l_{c,t} L_{c,t}. \tag{24}$$

and the firms' net worth evolves according to the following law of motion:

$$NW_{c,t} = NW_{c,t-1} + \Pi^*_{c,t-1} - T^\pi_{c,t} - DIV_{c,t}. \tag{25}$$

When the operating cash flows are positive ($\Pi^*_{c,t-1} > 0$), firms pay taxes on their profits ($T^\pi_{c,t}$) and distribute dividends ($DIV_{c,t}$) to the equity owners (capitalists), as follows

$$T^\pi_{c,t} = \begin{cases} \tau_t \Pi^*_{c,t}, & \text{if } \Pi^*_{c,t} > 0 \\ 0, & \text{otherwise.} \end{cases} \tag{26}$$

and

[9] Assumed to be constant and equal across firms. Caiani et al. (2018) and Caiani et al. (2017b) calibrate the values for these 'normal' rates by computing the steady-state solution of the aggregate model preceding the simulation.
[10] For simplicity, we assume that each loans lasts only one period.

$$DIV_{c,t} = \begin{cases} \rho(\Pi^*_{c,t} - T^{\pi}_{c,t}), & \text{if } \Pi^*_{c,t} > 0 \\ 0, & \text{otherwise.} \end{cases} \tag{27}$$

with τ_t indicating the tax-rate decided by the government (see subsection 2.7).

2.4. Households

We have $h = 1, \ldots, H$ households (workers and capitalists) consuming their income on the consumption goods market, saving in the form of bank deposits and paying taxes over their income. Only workers sell their labor force to consumption and capital firms, whereas capitalists only own firms and banks receiving dividends as a share of their profits.

2.4.1. Workers

Workers update each period their reservation wage depending on their occupational status, as follows

$$w_{w,t} = \begin{cases} w_{w,t-1}(1 + U[0,\delta]), & \text{if employed in } t-1 \text{ with } Pr(u_t) \\ w_{w,t-1}(1 - U[0,\delta]), & \text{if unemployed in } t-1 \end{cases} \tag{28}$$

with $Pr(u_t)$ indicating a positive probability for reducing the reservation wage (as for consumption firms).

The workers gross income is given by

$$y_{w,t} = w_{w,t} + i^d_{b,t} D_{w,t} \tag{29}$$

with $i^d_{b,t} D_{w,t}$ indicating the interest rate received on the bank deposits[11] and TF_t representing a tax-exempt transfer from the government[12].

2.4.2. Capitalists

The capitalists gross income is given by

$$y_{m,t} = DIV_{m,t} + i^d_{b,t} D_{m,t} \tag{30}$$

with $DIV_{m,t}$ indicating the dividends received by the firms/banks they own and $i^d_{b,t} D_{m,t}$ being the interests received on their deposits.

Capitalists may save their wealth ($NW_{m,t}$) either as deposit accounts $D_{m,t}$ or as investment in

[11] For simplicity we assume the same interest rate offered by the banking sector.

[12] These transfers represent the public expenditure in this model, as in Caiani et al. (2017a), see subsection 2.7.

firms/banks' equity $A_{m,t}$. The choice between these two assets depends on a certain degree of liquidity preference ($LP_{m,t}$) [13].

Thus, capitalists compute the desired level of wealth depending on their disposable income and the desired consumption, as follows

$$NW^D_{m,t} = NW_{m,t-1} + y^{DISP}_{m,t} - C^D_{m,t} \tag{31}$$

then they obtain the desired level of deposits and equity as

$$D^D_{m,t} = NW^D_{m,t} - (A^D_{m,t} - A_{m,t-1}) \tag{32}$$

and

$$A^D_{m,t} = \max\{A_{m,t-1}, (1 - LP_{m,t})NW^D_{m,t}\} \tag{33}$$

with $A^D_{m,t} - A_{m,t-1}$ indicating the desired investment in equity, which is bounded to be non-negative (Caiani et al. 2017a).

As for the other desired variables in the model, we could also have that $C^D_{h,t} > C_{h,t}$ (with $h = m, w$), and in the case of capitalist agents this means that $NW^D_{m,t} < NW_{m,t}$. In this case deposits act as a buffer stock variable with $A_{m,t}$ remaining at the planned level.

The disposable income for a generic agent on the household sector (worker or capitalist) is given by

$$y^{DISP}_{h,t} = (1 - \tau_t)y_{h,t} \tag{34}$$

with $h = w, m$ and τ_t indicating the tax-rate in the current period.

Each period, households also decide the desired quantity of consumption depending on their current disposable income and their wealth (i.e. bank deposits), as follows

$$C^D_{h,t} = \alpha_{1h} y^{DISP}_{h,t} + \alpha_{2h} D_{h,t} \tag{35}$$

with $0 < \alpha_{1h} < 1$ and $0 < \alpha_{2h} < 1$ and $\alpha_w > \alpha_m$.

Thus, the desired savings are

$$S^D_{h,t} = y^{DISP}_{h,t} - C^D_{h,t} \tag{36}$$

[13] See Caiani et al. (2017a), for a detailed description of how capitalists compute their liquidity preference. In the original model, the household sector is not composed by both workers and capitalists so households as a whole act as consumers, workers and equity owners. On the contrary, in the present model only capitalist agents may invest in equity asset.

2.5. Banks

We leave the banking sector functioning as well as the Government and the Central Bank behavior exactly as in Caiani et al. (2018). Thus, we have $b = 1, \ldots, B$ banks collecting deposits from households and firms (i.e. capitalists' deposits), offering an interest rate $i^d_{b,t}$ (which is a constant fraction of the discount rate i_t fixed by the central bank), they endogenously create means of payment by providing credit to consumption-good firms and they may purchase government bonds.
The probability of receiving credit by banks depends on the firms' leverage

$$Pr(L_{c,t}) = e^{-\iota \frac{L^D_{i,t}}{A_{i,t}}} \tag{37}$$

$$i^l_{c,t} = \chi \frac{L^D_{c,t}}{A_{c,t} + i_t} \tag{38}$$

with i_t indicating the discount rate fixed by the central bank.
The desired supply of loans depends on the banks' net worth

$$L^{SD}_{b,t} = \mu_1 A_{b,t} \tag{39}$$

and the maximum amount that a bank may provide to each firm is a maximum share of its supply ($\zeta L^{SD}_{b,t}$).
Commercial banks have a minimum amount of reserves to be held by the Central Bank as a proportion of their deposits

$$R^{min}_{b,t} = \mu_2 D_{b,t} \tag{40}$$

receiving a fixed interest rate i_{res}.
Then, banks may also spend the remaining amount of liquidity by purchasing government bonds $B_{b,t}$, yielding an interest rate i^b_t [14].
Thus, the banks' profit is given by

$$\Pi_{b,t} = \sum\nolimits_{c=1}^{C} i_{c,t} L_{c,b,t} + i^b_t B_{b,t} + i_{res} R_{b,t} - BD_{c,b,t} - i^d_t D_{b,t} - i_t L^{cb}_{b,t} \tag{41}$$

with $BD_{c,b,t}$ indicating the 'bad debt', that is the non performing loans due to firms' defaults. Also banks' profits are subject to taxation, and the net profit are eventually distributed to the equity owners as for firms (see equations 26 and 27).

[14] As in Caiani et al. (2017a) banks randomly access the bond market with a probability of purchase them, depending on the riskiness of the economy (i.e. the debt-on-GDP ratio): $Pr(b_t) = e^{-\iota \frac{B_t}{Y_t}}$.

2.6. Central Bank

We have a central bank that offers the cash advances (CA_t) requested by the commercial banks, holding their reserves ($R_{CB,t}$), and it eventually purchase the residual amount of government bonds ($B_{CB,t}$).
Also the central bank computes its profits and we assume that they are automatically distributed to the government, so we have

$$\Pi_{CB,t} = i_t^b B_{CB,t} + i_t CA_t - i_{res} RCB, t \tag{42}$$

2.7. Government

Government receives taxes from the households (capitalists and workers) and from firms and banks, thus

$$T_t = \sum\nolimits_{h=1}^{H} \tau T_{h,t}^{y} + \sum\nolimits_{c,\pi^*>0}^{C} \tau T_{c,t-1}^{\pi} + \sum\nolimits_{b,\pi>0}^{B} T_{b,t-1}^{\pi}. \tag{43}$$

Government public expenditure $G_t$is represented by the tax-exempt transfers to the households (TF_t).
In each period, government may has a budget surplus SUR_t or deficit DEF_t, so we have

$$DEF_t = G_t + i_{t-1}^b B_{t-1} - T_t \tag{44}$$

with the public debt defined as

$$B_t = B_{t-1} - DEF_t - SUR_{t-1}. \tag{45}$$

Finally, the interest rate on public bonds depends on the debt-on-GDP ratio and on the central bank's discount rate, as follows:

$$i_t^b = \chi_b \frac{B_t}{Y_t} + i_t \tag{46}$$

3. Simulation Results

The model has been ran for 1000 periods (each period corresponds to a quarter, thus we have a time-span of 250 years) and for 50 Monte Carlo simulations following a baseline calibration (see Table 5). Following Dosi et al. (2010) and Caiani et al. (2016) I check for the validity of the model by means of a minimum empirical validation. The model is indeed able to reproduce a collection of macroeconomic stylized facts as his ancestors (Caiani et al. 2016, Caiani et al. 2018 and Caiani et al. 2017a).

Figure 1 shows the cross-correlation functions related to cyclical component of some key macroeconomic variable. The position of the peak in each figure, that is to the left, centered or to the right, indicates whether the variable is, respectively, lagged, coincident or leading with respect to the other one. Cross-correlation functions of real consumption, public expenditure and wages with real GDP show that these variable are coincident and strongly pro-cyclical, whereas real investment, unemployment and public expenditure-GDP ratio are coincident and counter-cyclical. The cross-correlation of private saving with firms' wage share provides evidences for lower workers' propensity to consume. Moreover, cross-correlation between labor productivity and, respectively, real output and wages show that both a Kaldorian/Smithian and a Ricardian[15] mechanism boosts labor productivity dynamics within the present model.

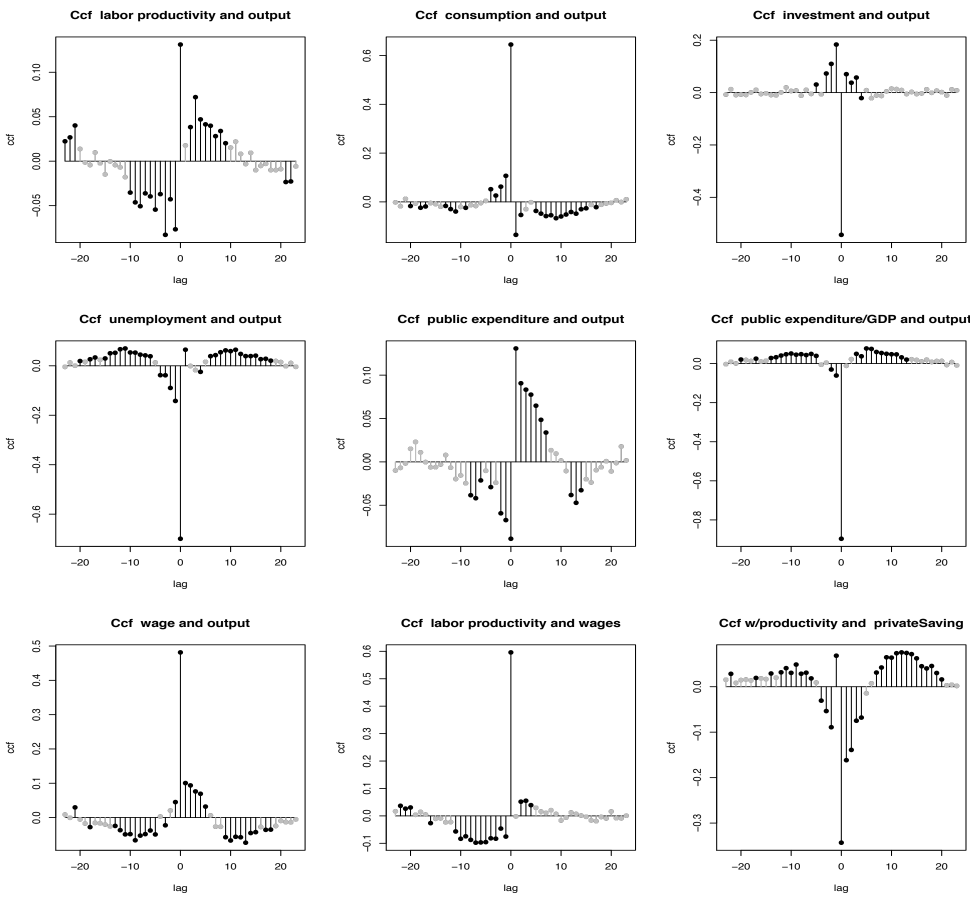

Figure 1. Average cross-correlations (across 50 Monte Carlo) of labor productivity, consumption, investment, unemployment, public expenditure, public expenditure-GDP ratio and wage with real GDP, average cross-correlations of labor productivity with wage, and of wage share with private saving.

Figure 2 represents the model dynamics showing the artificial time series related to some key variable during a single simulation run. As we can see the model shows self-sustained endogenous growth process, with exponential growth of real-GDP, real consumption and labor productivity

[15] For a detailed discussion about the so-called '*Smith*' and '*Ricardo effect*' in shaping technical progress dynamics in capitalist economies see Sylos-Labini (1983).

(Y/L), which follows the pattern of real-GDP (so-called '*Kaldor effect*' or '*Smith effect*'). Indeed, the analysis of the interplay among technical change and capital accumulation processes together with the pattern of wages and labor productivity is pivotal to understand the dynamics of our model at both micro and macroeconomic level. The model endogenously reproduces persistent fluctuations of aggregate wage share (i.e. total labor costs over total output or aggregate real wage-labor productivity ratio) due to different paces of the growth of wages and labor productivity (fig. 2). Thus, by definition we have that when real wages grow slower (faster) than labor productivity the wage share decreases (increases). However these fluctuations are driven by the predominance of two different economic forces during the technical change process.

On the one hand, firms are encouraged to improve their inputs' productivity by means of R&D investment, and thus by hiring workers for innovation and production activities, in order to increase their selling and conquer greater market shares. Therefore higher levels of R&D investments result in higher probability of innovating (eq. 15) so that more productive firms can also reduce their selling prices and improve their competitiveness as long as they achieve higher levels of productivity and greater market performances compared to their competitors. From a macroeconomic point of view these phases of 'virtuous circles' triggered by innovation and production processes driven in turn by greater sales expectations (that is by real consumption and aggregate demand) also improve aggregate employment dynamics creating positive feedback mechanisms for the overall economy. Of course some firms may suffer from productivity gaps and may have difficulties to sell production output and thus to increase their profit margins, however they may also try to catch up with leading firms by imitating their production technique (eq. 22). All in all, the 'Schumpeterian' evolutionary dynamics may leads more productive firms to survive whereas less productive ones may go bankrupt due to less willingness to grant credit by commercial banks (see in fig. 4 the dynamics of credit and firms survival) and due to difficulties to sell their product with an excessive stockpiling process.

Nevertheless, on the other hand firms also increasingly accumulate capital stock due to technological progress progressively improving labor productivity (to a greater extent than the improvement of capital productivity as shown in fig. 3), so that a greater amount of output can be produced by using less workers, as shown in fig. 2 with exponential growth of aggregate output-labor ratio as well as increasing '*capital-deepening*' [16] (fig. 5).

The predominance of these two opposite forces, that is virtuous innovative cycles and excessive labor-saving innovation pattern, also affects wage dynamics. Indeed more productive firms achieving greater market shares with higher levels of profitability and larger size in terms of internal financing and net worth are able to hire more workers for R&D and production activities, however on the other hand an excessive labor-saving pattern of technical change may lead to higher levels of unemployment thus weakening the bargaining power of workers as their wage claims are negatively affected by higher levels of unemployment (eq. 28). This negative feedback mechanism may be

[16] In this respect, we also compare our findings with the results provided by the ABM implemented by Delli Gatti et al. (2006).

further exacerbated when capital-good firms fail to absorb the workers fired by consumption-firms. Indeed, the increasing accumulation process of capital stock engaged by consumption-firms generate growing capital demand that cannot be continuously fulfilled given our assumption of fixed labor productivity for capital firms (i.e. we have capital shortage), thus capital-good firms try to hire an increasing amount of workers trying to satisfy the requested demand of capital goods[17].

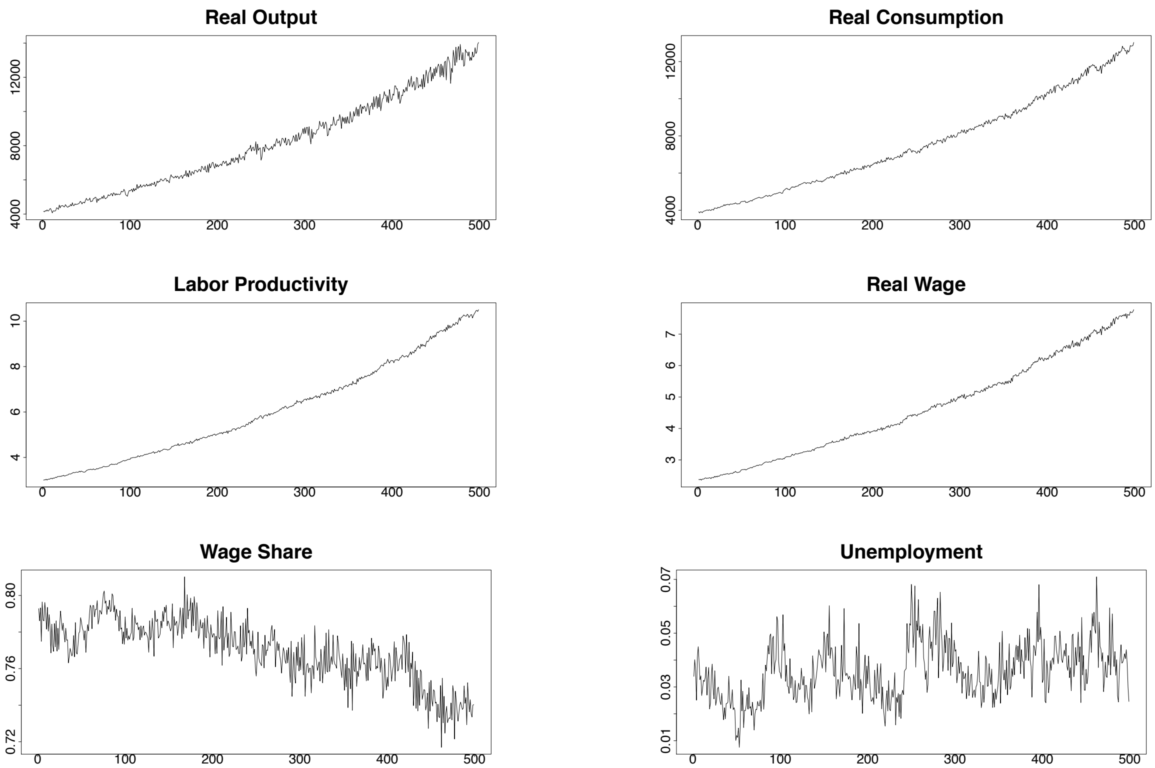

Figure 2. Artificial time series of Real GDP, (real) consumption, average labor productivity, average real wages, wage share for consumption-good firms and rate of unemployment for a single simulation run from time period 500 to 1000.

Moreover, as stated above firms do not innovate to the same extent in order to gain labor- or capital-productivity improvements, i.e. we have a '*directed*' and '*biased*' technical progress. Indeed, the pattern of the difference between average labor and capital productivity ($\varphi_{lt} - \varphi_{kt}$) shows (fig. 3) how the '*innovation bias*' endogenously emerges from the choice of techniques made by consumption firms, depending in turn on a classical profitability criterion (equation **??**), by means of different random draws from a symmetric support (equations 15 and 16) without imposing any '*Innovation Possibility Frontier*' á-la-Kennedy.

As pointed out by Stiglitz (2015) and Stiglitz and Greenwald (2015), a '*learning-to-learn*' process is at work, that is the factor-biased technical change process may feed upon itself as firms become more skilled at learning how to save the labor input.

[17] See Calvino and Virgillito (2018) for a detailed survey about different 'compensation' mechanisms proposed in literature in order to explain the interplay between innovation and employment.

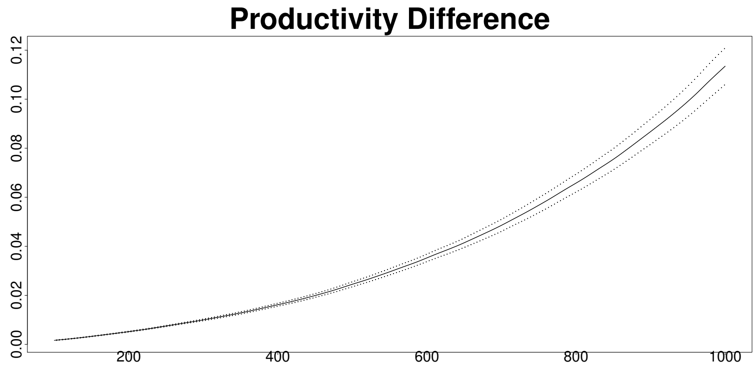

Figure 3. Percentage difference between average labor productivity and capital productivity, i.e. the difference between the inputs' productivity chosen from the random draws depending on the profitability criterion. Continuous and dashed lines indicate, respectively, average trend and trend standard deviation across 50 Monte Carlo simulations (from time period 100 to 1000).

In order to corroborate the hypothesis about the emergence of the innovation bias from the stochastic evolutionary technical change process, I investigate what happens in a 'counterfactual' scenario with *neutral* technical change (i.e. *Hicks-neutral*), that is with the same random draw for the growth rate of labor and capital productivity ($\hat{\varphi}_l = \hat{\varphi}_k$). Figure 4 shows the average trend components across 50 Monte Carlo runs for the artificial time series related to the baseline and the 'counterfactual' scenario. The artificial time series have been detrended by means of the Hodrick-Prescott filter and continuous and dashed lines indicate, respectively, average trends and trends standard deviations across the Monte Carlo runs. As we can see, in the 'innovation bias scenario' the direction of the choice of techniques towards an 'excessive' labor-saving technical change overall negatively affects the macroeconomic environment in our economy by weakening real-GDP and real consumption growth as a persistent slowdown of wages with respect to labor productivity (i.e. exacerbating faster growth of labor productivity with respect to wage growth) also reflects in contractions of the purchase power for workers, that is the class of households' agents with higher propensity to consume, leading to contractions of aggregate demand. Within the neutral innovation scenario firms almost indiscriminately chose improvement of both production input (labor and capital) without directing the innovation effort towards the input exerting higher pressure upon firms' cost structure (i.e. labor input). Hence, the neutral innovation hypothesis should not allows us to analyze the endogenous emergence of fluctuations in the labor share together with relatively higher levels of unemployment. Thus, the 'innovation bias' scenario allows us to provide a possible explanation for the endogenous emergence of persistent negative pattern of distributive shares as a consequence of 'non-neutral' technical progress.

As stated above, in the long-run the model is also able to reproduce the so-called '*Kaldor Stylized Facts*', thus, we have (fig. 5) increasing growth of output-labor ratio (i.e. the aggregated labor productivity), real wages (fig. 2) and growing capital-labor ratio (i.e. the '*capital deepening*') (fig. 5). According to the Kaldor facts, we also have roughly constant: distributive shares,

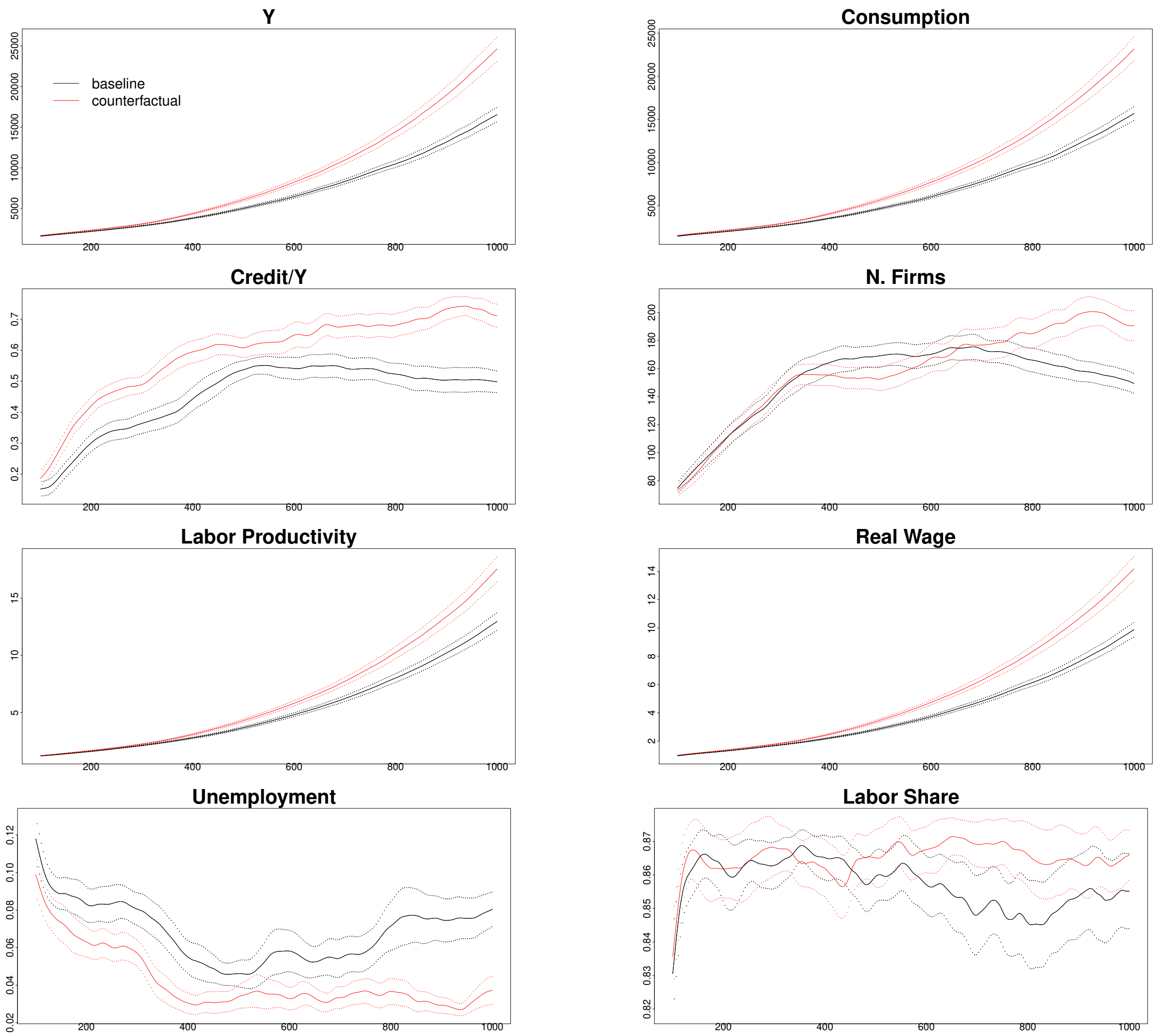

Figure 4. Average trends (continuous lines) and trends standard deviations (dashed lines) across 25 Monte Carlo simulations from time period 100 to 1000. I analyze two different scenarios: the 'baseline' scenario (black line) and a 'counterfactual' scenario wherein I implement a 'neutral' technical change process (red line).

average profit rate and output-capital ratio (i.e. the aggregated capital productivity) as shown in fig. 5. However, these are solely long-run phenomena. During the overall simulation, these variables show a richer dynamics. The average firms' profit rate shows decreasing pattern for long time periods until it stabilizes around its 'normal' value. Indeed the rate of profit it is a crucial variable either for firms' choice of technique and for their investment planning. Indeed, according to eq. 17 consumption firms discriminate among different productivity improvements depending on the expected profitability associated to new random techniques by trying to gain higher profitability due to an input-saving innovation process. However, many economic factors may lead to a 'fallacy of coordination' underling the aggregate pattern of the profit rate due to the relevant feedback mechanisms among technical change, wages, capital accumulation and the profit rate. For example, firms are profit-oriented and increasingly try to improve labor productivity by means of R&D activities in order to reduce the quantity of workers needed to expand their production and to improve the profit margins. However, as discussed above, an excessive labor-saving trajectory of technical change may be detrimental for the dynamics of wage as both firms and workers have a certain probability of reducing the offered and requested wage depending on the unemployment level in our economy (eq.12 and eq. 28). On the one hand the weaker dynamics of wages increases firms' profit margins though a reduction in the labor cost, but on the other hand it reduces the purchase power of the class with higher propensity to consume (that is, workers) thus weakening the aggregate demand. A contraction of the aggregate consumption may lead a greater number of consumption-good firms to suffer from weaker selling performances and lower revenues thus reducing in turns internal financing capacity and inducing higher loans demand to commercial banks (whose willingness to accord loan requests depends in turns on firms leverage and thus on firms' net worth). Moreover the ongoing capital accumulation process boosts the growth of firms capital stocks so to further deteriorate profit margins and thus the rate of profit. Then, we also observe decreasing output-capital ratio for the overall simulation until it stabilizes in the long-run, providing support for purely labor-augmenting technical change (i.e. *Harrod-neutral)* in the long-run but for labor-saving/capital-using technical change in the short- and medium-run. This trend is driven either by the accumulation of capital stock and by the faster growth of capital prices with respect to the inflation of consumption-good prices. Indeed, consumption firms may reduce their selling prices due to increasing productivity gains whereas in our model capital firms cannot undertake innovation activity in order to improve their production process and they are more constrained in reducing the price of capital goods for competitiveness purposes. Finally, as discussed above we observe fluctuations of the labor share, and particularly a falling trend for long time periods due to the innovation bias towards an excessive labor-saving technical change (fig. 4). Thus we can conclude that the magnitude of firms' capital accumulation process together with the direction of biased technical change if not offset by means of strong 'wage-push' forces (see section **??**) may lead to worse macroeconomic performances compared to the outcome obtained within the neutral innovation scenario.

We ought to highlight that in this model we focus our analysis on the effect of a 'non-neutral'

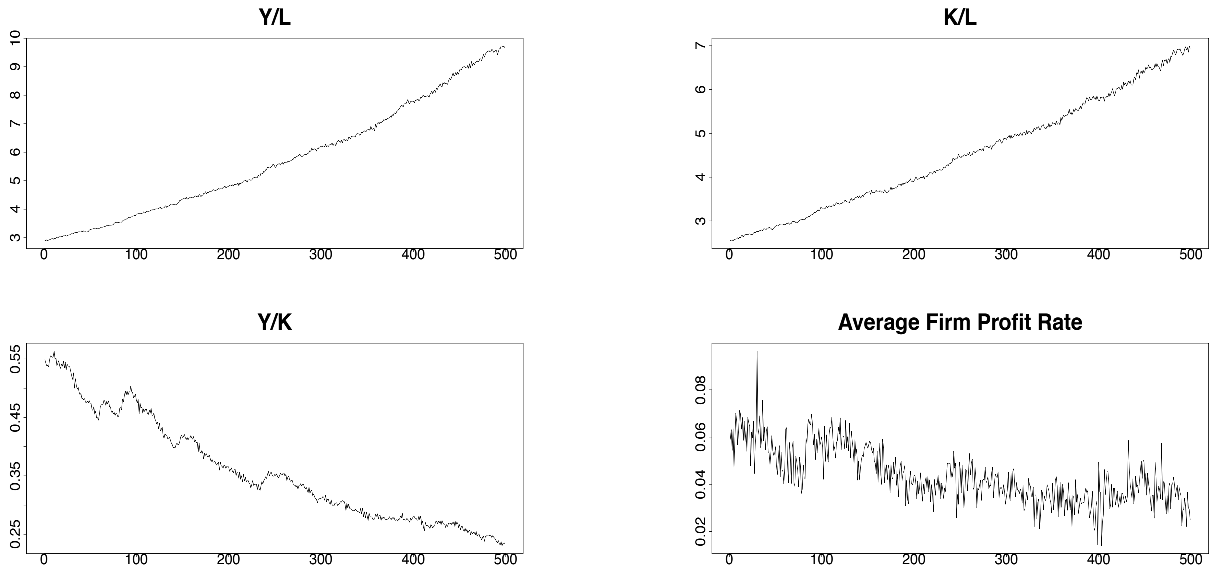

Figure 5. Artificial time series of output-labor ratio (Y/L), capital-labor ratio (K/L), average profit rate and output-capital ratio (Y/K) for a single simulation run from time period 500 to 1000.

technical change process upon long-run growth and *functional* income distribution, and that we are analyzing only *process* innovation. Thus, a more sophisticated model wherein we also consider *product* innovation and a segmented labor market, depending on different skills and/or different income-classes, would allows us to deeper analyze the interplay among technical change, growth, distributive shares and employment as we can consider, for example, the effects of different wage regimes upon different classes of workers. This is the case in Caiani et al. (2018) and Caiani et al. (2017b) wherein the effects of an excessive labor-saving technical change are not considered detrimental for growth and employment (or, *rectius*, wherein these effects are offset by a greater propensity to consume of lower-income workers) and where the higher levels of unemployment are explained as a consequence of growing income and wealth inequalities. However, a quite general dynamics has been presented for our artificial economy triggered by an excessive labor-saving technical change process which reproduces realistic patterns highlighted in theoretical and empirical contributions.

4. Sensitivity Analysis

A sensitivity analysis has been performed on the fiscal target for government's adaptive decisions about public expenditure and taxation (fig. 6), and on the initial wage offered by new created consumption firms during the simulation (fig. 7).

As in Caiani et al. (2017a) I implement a fiscal policy experiment, in order to assess whether restrictive (i.e. 'austerity' policies) or expansionary fiscal policies, have some effect on long-run growth, productivity, distributive shares and unemployment, besides affecting the overall macroeconomic performance of our economy. The fiscal policy experiment has been performed for different values of the maximum deficit/GDP ratio (d^{max}) representing the target for the adaptive decisions about public expenditure planning and tax rate revision by the government. This target is initially set to $d^{max} = 0.03$ (i.e. 'Maastricht constraint') in the 'baseline ' and then we change its value at period $t = 500$. The government follows an adaptive behavior rule in order to adjust the public expenditure and the tax rate[18], as follows:

$$\text{if } d_t \geq d^{max} \text{and } G_t^D \leq G_{t-1} : \begin{cases} G_t = G_{t-1}(1 - U[0, \delta] \\ \tau_{t+1} = \tau_t(1 + U[0, \delta]) \end{cases} \tag{47}$$

$$\text{if } d_t \geq d^{max} \text{and } G_t^D > G_{t-1} : \begin{cases} G_t = G_{t-1} \\ \tau_{t+1} = \tau_t(1 + U[0, \delta]) \end{cases} \tag{48}$$

$$\text{if } d_t < d^{max} \text{and } G_t^D \leq G_{t-1} : \begin{cases} G_t = G_{t-1}(1 - U[0, \delta] \\ \tau_{t+1} = \tau_t(1 - U[0, \delta]) \end{cases} \tag{49}$$

$$\text{if } d_t < d^{max} \text{and } G_t^D > G_{t-1} : \begin{cases} G_t = G_{t-1}(1 + U[0, \delta] \\ \tau_{t+1} = \tau_t \end{cases} \tag{50}$$

thus we define the fiscal policy as a revision of public expenditure and tax rate depending on the maximum fiscal target (d^max).

Figure 6 shows the average trend across 25 Monte Carlo simulations of real-GDP, labor productivity, capital and consumption-good prices, wages, real consumption and investment, number of consumption firms, credit-GDP ratio, R&D expenditure-GDP ratio, labor share and unemployment rate for different values of the maximum deficit/GDP ratio. The baseline scenario (black line) corresponds to $d^{max} = 0.03$ (i.e. the value imposed by the Maastricht Treaty), the restrictive scenarios are investigated with $d^{max} = 0.025$ (orange line), with $d^{max} = 0.02$ (red line) and $d^{max} = 0.015$ (red line), whereas the expansionary scenarios correspond to $d^{max} = 0.035$ (light blue line) and $d^{max} = 0.04$ (blue line). As we can see, a restrictive (expansionary) fiscal policy exerts negative (positive) long-run effect upon growth and distribution in our artificial economy. In line with the results provided by Caiani et al. (2017a), we find that an expansionary (restrictive) fiscal policy positively (negatively) affects the macroeconomic performance of our economy showing stronger (weaker) growth patterns of real-GDP, labor productivity, consumption and investment, as well as an improvement of consumption- and capital-good prices and wages dynamics. A virtuous (viscous) dynamics of growth and productivity also reflects on credit dynamics as firms with greater profit margins can successfully apply for bank loans in order to expand their production and innovation activities (see the pattern of innovation expenditure over GDP ratio), and on the

[18]See Caiani et al. (2017a) for a detailed discussion of this adaptive fiscal rule and the effects of different fiscal target scenarios in a multicountry monetary union model.

‘Schumpeterian’ competitive race among firms showing a greater number of firms surviving under the two expansionary scenarios (the opposite occurs under the restrictive scenarios). Furthermore, the positive effect exerted by an expansionary fiscal target also reflects in higher labor share and lower unemployment rate. Thus we can say that the detrimental effects exerted of the innovation bias upon growth and distribution in our economy can offset by an expansionary Keynesian fiscal policy.

Furthermore, as stated above, the sensitivity analysis has been also performed on the initial wage (w_0) offered by firms and then revised during the simulation following the adaptive rule (eq. 12) described in section 2.3.1. As discussed in section 3, within our artificial economy the magnitude of firms’ capital accumulation process together with the direction of biased technical change may lead to worse macroeconomic performances compared to the outcome obtained within the neutral innovation scenario, thus we analyze the effect of an increase in the initial wage offered by new firms during the endogenous entry/exit process[19]. As we can see in figure 7, the so-called ‘paradox of costs’(Kalecki 1971) holds in our economy. Thus, an increase in the initial wage offered by firms gives a positive stimulus to the dynamics of growth and labor productivity through the positive effect of the aggregate demand, that is due to an increase in the purchase power of workers reflecting in turns in greater aggregate consumption.

[19]see Caiani et al. (2017a) for a detailed description.

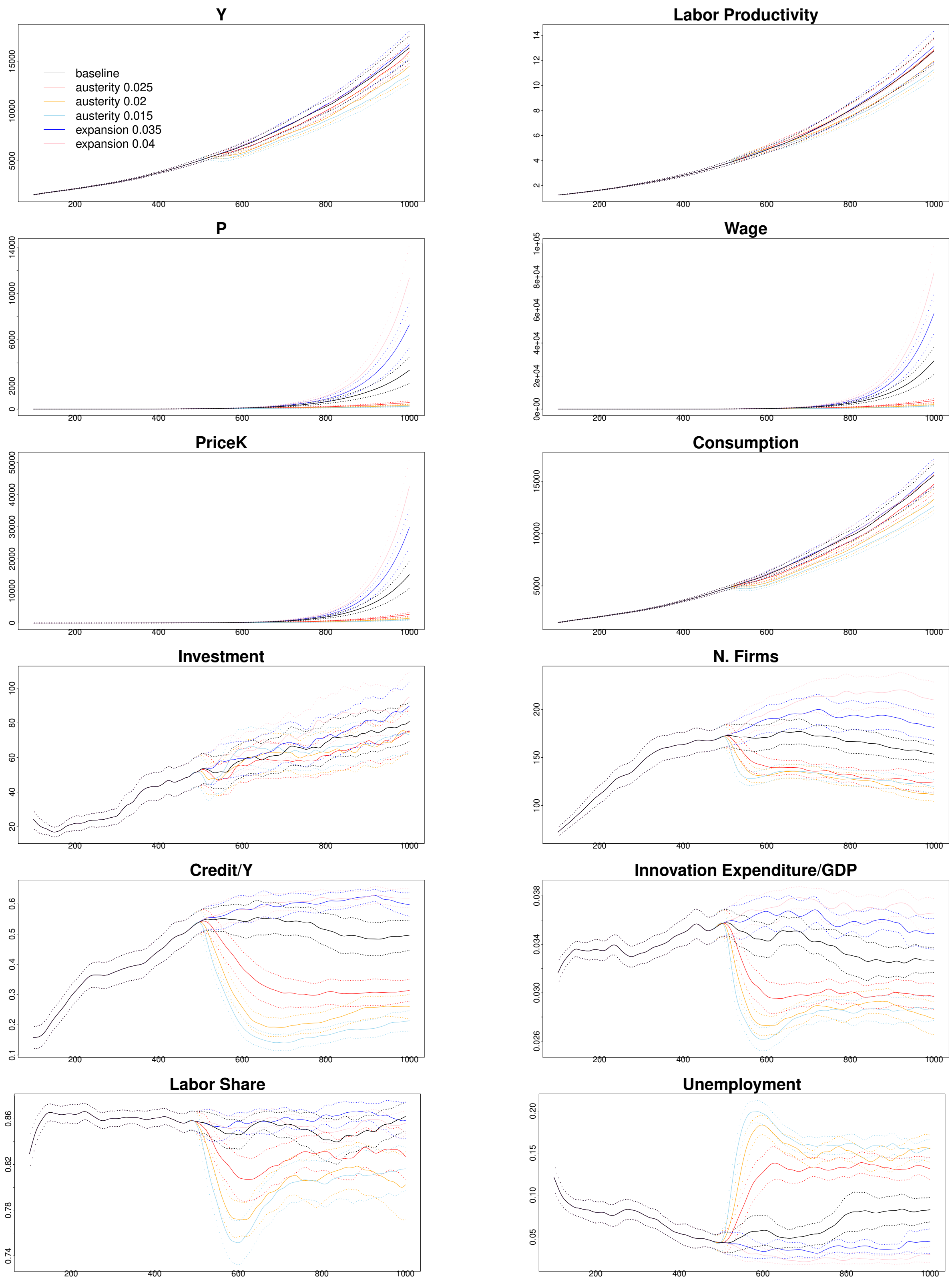

Figure 6. Average trends (continuous lines) and trends standard deviations (dashed lines) across 25 Monte Carlo simulations. We have the 'baseline' scenario (black line) with $d^max = 0.03$ and then three restrictive ('austerity') scenario with $d^max = \{0.025; 0.02; 0.015\}$ (respectively, red, yellow and light blue line) and two expansionary scenarios with $d^max = \{0.035; 0.04\}$ (respectively, blue and pink line).

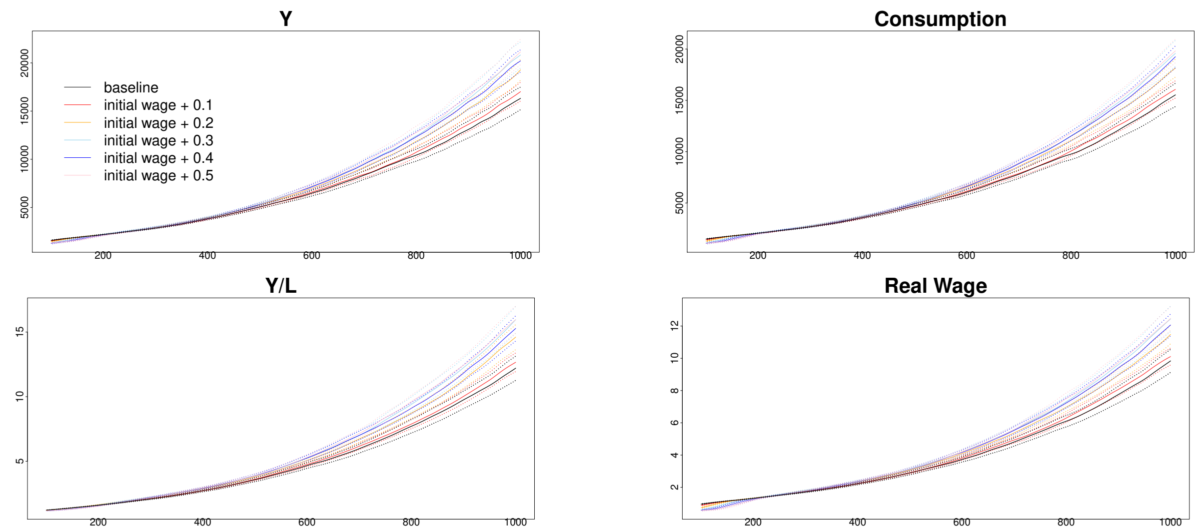

Figure 7. Average trends (continuous lines) and trends standard deviations (dashed lines) across 25 Monte Carlo simulations.We compare the baseline scenario (black line) with different scenarios representing the pattern of real output, consumption, aggregate labor productivity and real wages with progressively higher values of initial wage (w_0).

5. Conclusions

The main strength of the present contribution concerns the integration of a *classical-fashioned* induced and directed innovation process within a *Keynesian* demand-led and *evolutionary* endogenous growth model. The AB-SFC macro modeling approach allows us to analyze the *innovation bias* as an *emergent property* of the technical change process engaged by heterogeneous consumption-good firms choosing both the *intensity* and the *direction* of the innovation towards a labor- or capital-saving choice of technique.

In the long-run the model reproduces the so-called 'Kaldor Stylized Facts' (i.e. we have a purely labor-saving technical change), however during the transitional phases the model shows a labor-saving/capital using innovation pattern as the aggregate output-capital ratio decreases until it stabilizes in the long-run. Moreover, the model reproduces endogenous fluctuations of labor share with a declining pattern for long time periods and we can ascribe this evidence to the directed and biased technical change process. Indeed, the comparison between the baseline scenario with the '*counterfactual*' scenario wherein a '*neutral*' technical progress is at work, confirms our hypothesis showing weaker growth of both real-GDP and real consumption within the 'innovation bias' scenario as well as persistent downswings in labor share and relatively higher unemployment rate with respect to the 'neutral innovation' scenario. Of course, this is just a first step towards the analysis of the interplay among biased technological change, employment, growth and income distribution. Indeed, there are many aspects that should be further investigated starting from this model. For instance, the analysis of technical progress implemented within the present model exclusively considers process innovation in a closed-economy model, whereas further investigations could also concern product innovation and competitiveness gaps between two (or even more) countries. Such an approach would allows us to analyze, for instance, the non-convergence issues affecting the core-periphery asymmetrical structure of the European Monetary Union (EMU).

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A Baseline calibration

Symbol	*Description*	*Value*
W	Number of workers	1500
M	Number of capitalists	100
Ψ	Matching Parameter	10
A_0	Firms' initial net worth	10
u	Wage revision probability parameter	2.0
φ_{l0}	Initial labor productivity (consumption firms)	1.0
φ_{k0}	Initial capital productivity (consumption firms)	1.0
a_K	Labor productivity (capital firms)	2.0
w_0	Initial wage	1.0
p_0	Initial consumption-good price	1.0
δ	Adaptive parameter	0.03
ρ	Share of dividends distributed	0.95
γ	Share of R&D expenditure	0.03
ν	R&D success probability parameter	1.0
$\mu_{c,0}$	Consumption firms' initial mark-up	0.2
$\mu_{k,0}$	Capital firms' initial mark-up	0.04
θ	Inventories share parameter	0.2
κ	Capital goods duration	20
δ_1	Investment function profit rate weight	0.025
δ_2	Investment function capacity utilization weight	0.025
$\overline{r}$	'Normal' profit rate	0.045
$\overline{u}$	'Normal' rate of capacity utilization	0.9
α_{1w}	Workers' propensity to consume out of income	0.95
α_{2w}	Workers' propensity to consume out of wealth	0.35
α_{1m}	Capitalists' propensity to consume out of income	0.65
α_{2m}	Capitalists' propensity to consume out of wealth	0.15
η	Banks-firms minimum proportion	0.03
σ	Banks' minimum dimension relative to firms	4.0
μ_1	Total credit supply parameter	20.0

μ_2	Minimal reserve requirement parameter	0.1
χ	Loan interest parameter	0.003
ι_l	Loans' probability parameter	0.2
ι_b	Bonds' probability parameter	0.1
τ_0	Initial tax rate	0.4
G_0	Initial public expenditure	0.4
i_{res}	Interest paid on banks' reserves	0.001
i_0^b	Initial interest rate on bonds	0.001
ζ	Deposit interest-discount rate ratio	0.1